AN INVESTIGATION OF THE CHARACTERISTICS
OF MECHANICAL FILTERS

By

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PREFACE

There have been many investigations of rapid sand filters as a unit, and on various parts of the rapid sand filters, but to my knowledge there have been no investigations where a study has been made on the characteristics of rapid sand filters when there is a difference in the make up of each unit, filtering the same treated water and operated under normal conditions.

Some of the conclusions drawn from the experimental data in this thesis have been supplemented by personal experiences and observations during my employment as operator at the College Water Treatment Plant.

I wish to acknowledge and express my sincere appreciation for the guidance and helpful suggestions of Professor Quintin B. Graves, under whose direction this work was accomplished at the Oklahoma Agricultural and Mechanical College, Water Treatment Plant.

Many thanks are due Messrs. Lawrence Paxton, Frank Smith, Gus Johnson, Donald Burns, and Robert Matthews, operators of the Water Treatment Plant, without whose cooperation these experiments could not have been effected.

To my wife, Iris, for her years of loyalty, understanding, and able assistance, I dedicate this thesis.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Acre
^{o}F	-	Degree Fahrenheit
Eff.	-	Effluent
Ft.	-	Feet
Hrs.	-	Hours
"	-	Inches
Inf.	-	Influent
MO	-	Methyl Orange
mm	-	Millimeter
MGD	-	Million gallons per day
Min.	-	Minute
No.	-	Number
#	-	Number
P	-	Phenolphtalein
pH	-	Hydrogen-ion Concentration
ppm	-	Parts per million

CHAPTER I

INTRODUCTION

The earliest artificial water supplies were probably shallow dug wells, scratched out by hand in moist localities; however, as men gathered for protection and other reasons, these shallow wells would no longer serve their purpose and other sources of water supply were sought.

Lake Moeris in Egypt was the earliest known artificial lake supply and there are indications that it was constructed about 2000 B.C. Also, Biblical references to water works are frequent.[1]

As the cities grew larger and more crowded, it became evident that a pure water was needed. This quest for pure water dates back to approximately 1450 B.C. as pictured on the wall of the tomb of Amenophis II at Thebes; also, reference to the purification of water is noted in II Kings 2:19-22.

An attractive water is not always a safe water; therefore, in order that people will drink and use safe water, it must be attractive; otherwise, people will turn to the unsafe water just because "it looks good".

The quality of water is judged by several related characteristics which are dependent upon a number of biological, physical, and chemical phenomena. For this reason, the measurement of quality is difficult and cannot be fully determined by a measurement of only one of its characteristics.[2] Since this thesis is mainly concerned with the physical character-

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[1]Harold E. Babbitt and James J. Doland, Water Supply Engineering, Third Edition, 1939, Page 1.

[2]Earle L. Waterman, Elements of Water Supply Engineering, Second Edition, 1949, Page 46.

istics, the main discussion will follow this theme.

The physical examination of water consists of the determination of turbidity, color, odor, tastes, and temperature.

The temperature of water for a municipal supply should be between 45° F. and 50° F., if the temperature is too high, the water is less palatable, which is probably due to the absence of dissolved gases. If the temperature is too low, it is more difficult to treat.

Odor in water is closely associated with taste and these two are least tolerated by the public. Taste and odor are caused by such things as vegetable matter in solution, biological agents, and sometimes by poor control of the treatment of the water.

Color in water is due to mineral and/or organic substances in solution.

This leaves turbidity, and since it is the major reason for filtration, it is perhaps desirable for a more complete discussion of this subject. Turbidity refers to the clearness of water. A turbid water is one that carries suspended matter which obstructs the passage of light. It may be due to silt, clay, suspended iron, organic matter, or microorganisms.[3] The standard unit of turbidity is defined by the American Public Health Association as that produced by one part per million of silica (diatomaceous earth or Fuller's earth) in distilled water.[4]

As aforementioned definition implies, turbidity may be caused by mineral, plant, or animal; therefore, it may be well to further discuss turbidity due to each of these categories.

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[3]Ibid, Page 55.

[4]American Public Health Association and American Water Works Association, Standard Methods for the Examination of Water and Sewage, Page 10.

The mineral turbidity is of very little importance as to the safety of its use as a drinking water, but there is a decided aversion on the part of the consumer to using a turbid water.

The presence of microscopic organisms in the water which is to be filtered sometime may result in short filter runs, and certain iron bacteria cause unsatisfactory conditions with respect to turbidity. Most bacteria found in water supplies are harmless; however, a few are very harmful. These are the pathogenic or disease-causing bacteria.

Among the best known specific diseases, whose germs can be carried by water, are typhoid fever, dysentery, and cholera. These three pathogens are not taken out by filtration, but are destroyed by other means. The Protozoa are minute animals consisting of but a single cell and are distributed widely in all surface water and in the soil. These animals cause more odor than turbidity of the water. Another group is the Metazoa of which many are microscopic in size, but a number are visible to the naked eye. In some cases, these animals may be in such a large quantity as to shorten the filter runs. As a specific case, one period during the collection of data for this thesis, there was a large influx of Crustaceae or Fairy Shrimp on the filters, which, if they had continued, would have shortened the filter run considerably.[5]

Algae is one of the plants which cause trouble with tastes and odor, but cause no ill-effects to man. If the plant life is small in size, and concentration in the water is small, it is doubtful if there is much turbidity due to these plants.

As heretofore mentioned, the prime purpose of most filters is the removal of turbidities for the clarification of water and not the removal

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[5]F. E. Turneaure and H. L. Russell, Public Water Supplies, Fourth Edition, 1948, Pages 178-182.

of disease-causing organisms. The reason for this is that most of the disease-causing organisms will pass through the filter medium; therefore, it is safer to depend on other means of killing these organisms and depend upon the filters for removing turbidity only.

Water filtration may be described as the process by which water is separated from the suspended impurities it contains by passing it through a porous substance, such as a bed of sand. This process is effected by three general types of sand filters: slow sand filters; pressure filters; and rapid sand filters.[6]

Slow sand filters operate with the water applied passing through deep beds of fine sand at a low velocity. These filters are not generally practical for highly turbid waters. There need not be preliminary treatment of the water, as the successful operation of slow sand filter depends upon the "schmutzdecke," which is the surface layer containing a zoogloeal jelly in which the biological activities are at their highest.[7]

Pressure filters are used mainly in swimming pools and industrial work as there are too many objections for use in municipal supplies. In recent years, there have been improvements on pressure filters, particularly those using diatomaceous earth as a filter medium.[8]

Since this thesis is concerned only with the characteristics of rapid sand filters, the remainder of the discussion will be on these characteristics. Also, it may be noted that rapid sand filters are

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[6] American Society of Civil Engineers, Water Treatment Plant Design, 1940, Page 49.

[7] Harold E. Babbitt and James J. Doland, Water Supply Engineering, Fourth Edition, 1949, Page 461.

[8] Warren E. Hoxworth, The Effectiveness of Diatomaceous Earth Filters on Lake Carl Blackwell Water, Thesis - 1951.

known as mechanical filters or American filters, but for clarity they will be referred to as rapid sand filters throughout the remainder of this thesis.

Rapid sand filters, as the name implies, have a very rapid rate of filtration; almost 60 times greater than that of a slow sand filter. At the present time, the rate is two (2) gallons per square foot per minute, but some plants are running at three (3) gallons per square foot per minute, and experiments are now being carried out at the rate of five (5) gallons per square foot per minute.

Unlike slow sand filters, the rapid sand filters depend on pre-treatment of the water before filtering; also, in slow sand filters a deep bed of fine sand is used whereas in the rapid sand filter a shallow bed of coarse, uniform, graded sand is used. The use of a coagulant to form an artificial "schmutzdecke" is essential to the operation of a rapid sand filter, according to some authorities.[9]

Much has been written as to the filtering action of a sand bed, and several theories advanced to account for the removal of bacteria and particles that are smaller than the spaces between the sand grains, but it is generally accepted that when the water is properly treated, a large percentage of the suspended matter, including bacteria, is collected in the floc. When the floc reaches the sand bed, most of it enters the spaces between the sand grains, and here each interstice acts as a miniature coagulation basin where the floc builds up until the particles are large enough to be strained out by the constrictions between the pores.

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[9]Harold E. Babbitt and James J. Doland, Water Supply Engineering, Fourth Edition, 1949, Page 466.

This process continues until the pores become so clogged that the burden of removing more of the particles is shifted deeper into the sand bed, and if this continues for a long period of time, the filter wil eventually pass the suspended matter through the filter bed.[10]

Many experiments have been made and many theories have been expounded as to the size of sand which should be used for rapid sand filters, and inasmuch as these are too numerous to mention, we shall list only one. The effective size of sand (Hazen's) ordinarily used is between 0.40 and 0.55 mm, with a uniformity coefficient not greater than 1.8.[11]

Materials used in rapid sand filters, other than sand, are crushed and graded anthracite, glass, and proprietary products. The advantages claimed by using anthracite coal are: longer filter runs; lower backwashing velocity; and greater porosity.

The sand in a rapid sand filter is supported on nine to eighteen inches of graded gravel. The purpose of the gravel is twofold: one, to prevent sand from entering the underdrains; and, two, to aid in a uniform distribution of wash water. When anthracite coal is used for a filter media, there is no gravel needed, inasmuch as the anthracite is graded to take care of both the sand and gravel.

Under this layer of sand and gravel is a collection and distribution system, which is the underdrains. They also serve two purposes: one, to collect the filtered water; and, two, to distribute the wash water

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[10] American Society of Civil Engineers, Water Treatment Plant Design, 1940, Page 50.

[11] Committee Report, Filter Sand for Water Purification Practice, Proceedings American Society of Civil Engineers, Vol. 62, 1946, Page 1543.

uniformity. There are several different types of underdrains, including perforated pipes; pipe and strainers; perforated plates; ridge and valley; and porous plates.

In summation, this introduction has endeavored to show a number of items. Among these are: a short history of water; the physical properties of water with emphasis on turbidity; the causes of turbidity; a short discussion on types of filters; and, finally, a discussion of the rapid sand filter, whose main purpose is the removal of turbidity.

CHAPTER II

REVIEW OF PREVIOUS INVESTIGATIONS

It was pointed out in the previous chapter that there are two distinct phases in the operation of a rapid sand filter. They are the preparatory treatment, and filtration; therefore, it is obvious that since raw water varies even in the same general locale, the successful operation of rapid sand filters depends on the preparatory treatment; however, since this thesis is concerned with the characteristics of rapid sand filters, it will be assumed that preparatory treatment is satisfactory.

In previous investigations of rapid sand filters, many variations and adaptations of general methods have been used, among which are:

(1) Size, depth, uniformity, and texture of the filtering media.

(2) Length of filter run, loss of head, rate of flow, temperature of water, and percentage of removal of turbidity.

(3) Type of filter bottom.

(4) Velocity of applied wash water, height of wash water gutter above sand bed, shape and spacing of wash water gutters, and efficiency of filter wash.

It has been shown on small experimental filter beds that the depth of the sand beds are proportional to the squares of the average diameters of the sand grains, provided the grains are of uniform size and have equal filtering ability.[12] Hazen's experiments set up two values, effective

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[12] American Society of Civil Engineers, Water Treatment Plant Design, 1940, Page 62.

size and uniformity coefficient, where effective size of sand is the size of grain such that ten per cent (10%) by weight of the sands are smaller than that size. The size is expressed as the diameter in millimeters. The uniformity coefficient is expressed as the ratio of the size such that sixty per cent (60%) by weight is smaller, to the effective size. L. A. Allan suggested the formula for determining the depth of a filter bed when a sieve analysis of the sand, and the critical depths of its various grades are known:

$$d_t = \frac{(d_m + d_f)\ 100}{p_f}$$

where d_t = total depth of sand to be placed.

d_m = the computed minimum depth of sand in inches.

d_f = a depth of sand, in inches, as a factor of safety.

p_t = a total percentage of sand, by weight, as shown by sieve analysis.[13]

G. M. Fair and L. P. Hatch attempted to develop a clear conception of the flow of water through sand from Poiseuille's law, and found that in order to find the loss of head through a clean filter bed, the following must be known:

(1) Depth of bed.

(2) Temperature of water.

(3) Porosity ratio of the bed.

(4) Rate of filtration per unit filter area.

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[13] L. F. Allan, Filter Sand Experiments, Journal American Water Works Association, 1935, Page 205.

(5) Shape of sand.

(6) The size-weight distribution of the sand as determined by a sieve analysis.[14]

T. R. Camp found that more factors should be added to those found by Fair and Hatch; these are: one, length of filter run; two, quantity of suspended matter; and, three, size of the suspended particles.[15]

There have possibly been more experiments on types and kind of filter bottom than on any other phase of filtration. The following are only a few:

(1) R. S. Weston, Wheeler Filter Bottom;

(2) H. N. Jenks, Cemented Gravel Slab Vitrified-Clay Pipe;

(3) T. R. Camp, Porous Plates;

(4) J. W. Ellms, Perforated Pipe Strainer;

(5) C. I. Lauter, Slat Bottoms;

(6) W. N. Jones, Using Brass.

J. R. Baylis made an extensive study of the relation between rate of filtration and the time the filter runs between washings and concluded that:

$$H = \frac{K}{M^{1.5}}$$

H = filter run in hours.

K = a constant depending on clogging tendency of the water. This varies between 52 and 90.

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[14] G. M. Fair and L. P. Hatch, Fundamental Factors Governing the Streamline Flow of Water through Sand, Journal American Water Works Ass'n. Nov. 1933.

[15] T. R. Camp, Filter Sand for Water Purification Plants, Proceedings American Society of Civil Engineers, Part I, April,1937.

M = rate of filtration, gallons per square feet per minute.[16]

There have been other phases discussed at great length such as width between wash water gutters; height of gutter above the sand; arrangement and shape of gutters; sand expansion; and amount of washing.

All of the foregoing discussion has applied to only phases of rapid sand filtration, and not to the general characterizations as a whole.

The experiments on the characterizations of rapid sand filters have been quite extensive. To point out a few, reference is made to Table I.[17] It will be noted that each of these plants differs from the other in depth of sand, type of underdrain, etc., but in the individual plant itself, the sand depth, type of underdrains, etc., are the same. To the best of the author's knowledge, this is the only investigation of rapid sand filters where there is not only a difference of filter media, but also a difference in underdrains of four filters where the same treated water is filtered.

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[16]J. R. Baylis, Experiences in Filtration, Journal American Water Works Association, July, 1937, Pages 1010-1044.

[17]F. E. Turneaure and H. L. Russell, Public Water Supplies, 1948, Page 474.

DATA ON RAPID SAND FILTERS

FILTERS	ALBANY	CLEVELAND	KANS. CITY MO.	NEW ORLEANS	ST. PAUL	ST. LOUIS	STILLWATER, OKLA. NO. I	NO. II	NO. III	NO. IV
Date Operation Began	1931	1924	1928	1931	1923	1921	1950	1950	1950	1950
Normal Capacity, MGD	32	165	96	72	42	80	1	1	1	1
Number of Units	8	40	24	18	12	20	1	1	1	1
Dimension of Sand Bed, Ft.	2-15x46	2-14x49	2-14-50	2-13x53	3-14-42	28x5	18x20	18x20	18x20	18x20
Depth of Sand, Inches	30	30	27	30	27	24	30	30	30*	30
Size of Sand, mm	.33	.38	.41	.33	.38	.4-.5	.47	.47	.7-.8	.45
Uniformity Coefficient	1.75	1.70	1.55	1.65	1.75	1.65	1.15	1.16	----	1.18
Rate of Wash Water, Inches per Min.	24	24-36	24	24	24	20	24-27	24-27	20	24-27
Top of Sand to Wash Trough, Inches	27	25	24	36	22	20	25	25	24.5	25
Clear Distance between Troughs, Ft.	4.57	4.93	4.33	6.62	4.50	3.73	4.42	4.42	4.42	4.42
Per Cent Wash Water Used	2.5	2.08	1.37	0.3	3.0	1.25	1.3	2.5	0.4	2.0
Type of Strainer	C	B	B	B	E	B	B	A	B	D
Rate of Filtration MGD per A	125	160	125	122	125	125	125	125	125	125
COAGULATING BASINS							ACCELATOR		CONVENTIONAL	
Time of Mixing, Min.	20	Jump	30	60	33	16	47 min.		15	
Time of Coagulation, Hrs.	2.25	4.65	12.5	18	3.8	8.7			1.0	
Velocity, Ft. per Min.	1.5	2.4	0.6	0.55	3.0	2.3			2.04	
Length, Ft.	200	693	309	345	220	330	21.0		30.0	
Width, Ft.	50	110	333	250	110	406	21.0		24.0	
Depth, Ft.	10-18	9-18	17	14	15-19	15	13.0		11.0	

A - Wagner Block B - Perforated Pipe Laterals C - Pipe Laterals and Brass Strainers * Anthrafilt

TYPE OF STRAINER

D - Leopold Glazed Tile Compound Duplex E - Wooden Slat Grid

TABLE I

CHAPTER III

THE GENERAL PROBLEM

The purpose of this thesis is to determine the characteristics of four different filters while functioning under normal operating conditions. A complete description of each filter is given in Chapter IV.

As previously stated, one of the main characteristics of rapid sand filters is the ability to remove turbidity while filtering at a high rate of filtration, and not necessarily any removal of bacteria, particularly organisms of the "coliform group".

Keeping this in mind, it was decided that samples of the water on the filters and samples of the water out of the filter would be collected six times daily: 0400, 0800, 1200, 1600, 2000, and 2400 hours. The samples were then to be tested for the following: turbidity; alkalinity; and pH. Also, once each day a standard sample would be collected and standard methods used in testing for coliform and bacteria. The temperature of the raw water was taken daily.

To further determine characteristics and efficiency, a record was to be kept of: hours of filter run between washing; total gallons filtered between washing; loss of head between washing; amount of wash water used; per cent of wash water; and note made of any change of treatment. In order to facilitate a more even operation of each filter, it would seem that if one filter was operated at a constant design rate (1 M.G.D.) and the other three operated at varied rates for a twenty-four hour period of time, and then this method rotated to each filter, the above would be accomplished to a greater degree of accuracy than if it were left to the individual operator.

CHAPTER IV

DESCRIPTION OF EQUIPMENT

I. Filters

All filters have the same design of collection manifold built into the concrete of the filter box and each type of filter is adapted to use this collection manifold. Figure No. I shows a typical cross section of the filters. All filters have the same type of operating tables, gauges, and controllers.

A. Filter No. I is equipped with a system of standard cast iron pipe underdrains, consisting of three-inch cast iron laterals on twelve-inch centers, the laterals having a seven-sixteenths inch orifice at approximately six-inch centers. The gravel is placed to a total depth of eighteen inches with the following depths and sizes:

Layer No.	Depth	Passing Mesh
1	5"	2-1/2"
2	3"	1-1/4"
3	3"	3/4"
4	3"	1/2"
5	4"	1/4"

The filter sand is prepared according to approved practice and placed to a depth of thirty inches. It has an effective size of .47 and a uniformity coefficient of 1.15.

B. Filter No. II is equipped with the Wagner Bottom type underdrain system as furnished by Infilco, Inc., consisting of concrete distributing blocks between the laterals. This is shown in Figure No. II. The gravel is placed to a total of thirteen inches with the following depth and sizes:

Layer No.	Depth	Passing Mesh
1	3"	1-1/4"
2	3"	3/4"
3	3"	1/2"
4	4"	1/4"

The filter sand is placed to a depth of thirty inches. It has an effective size of .475 and a uniformity coefficient of 1.16.

C. Filter No. III is equipped with the same underdrain system as Filter No. I, but in this filter there is placed thirty inches of #1 Anthrafilt, which rests on the following sizes of Anthrafilt:

Number	Depth	Size
#6	6"	13/16" - 1-5/8"
#5	4"	9/16" - 13/16"
#4	3"	5/16" - 9/16"
#3	2-1/2"	3/16" - 5/16"
#2	2-1/2"	3/32" - 3/16"

D. Filter No. IV is equipped with fire clay tile block manufactured by F. B. Leopold Co., Pittsburgh, Pennsylvania, which is a "Duplex Filter Bottom." This is shown in

Figure No. III. The gravel is placed to a total of ten inches with the following depth and size:

Layer No.	Depth	Passing Mesh
1	3"	3/4"
2	3"	1/2"
3	4"	1/4"

The filter sand is placed to a depth of thirty inches. It has an effective size of .45 and a uniformity coefficient of 1.18.

Figure No. IV is a view of Filter No. II with the water drawn down, showing the filter bed, wash water trough, control float, and hydraulic piping. These general features are in all four filters.

II. Turbidimeter

The Hellige Turbidimeter was used to run all of the turbidity tests. A photograph of this equipment is shown in Figure V.

III. pH Meter

The Beckman Model H-2 pH meter was used to determine two things:[18]

A. Any change in the hydrogen-ion concentration;

B. Measurement of the alkalinity expressed in terms of the equivalent weight of calcium carbonate. This will be explained in more detail later.

Figure VI shows this pH meter and accessory equipment used with the pH meter.

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[18] Instructions for Beckman Fiber Type Reference Electrodes, Bulletin 256, Beckman Instruments, Inc.

IV. Incubator

The incubator was used to run tests for the coliform group and run tests for bacteria plate count. The incubator was maintained at a constant temperature of 37° C.

V. Refrigerator

The refrigerator was used to store culture media at a reduced temperature.

VI. Quebec Colony Counter

This equipment was used to aid in a more accurate count of bacteria from plates.

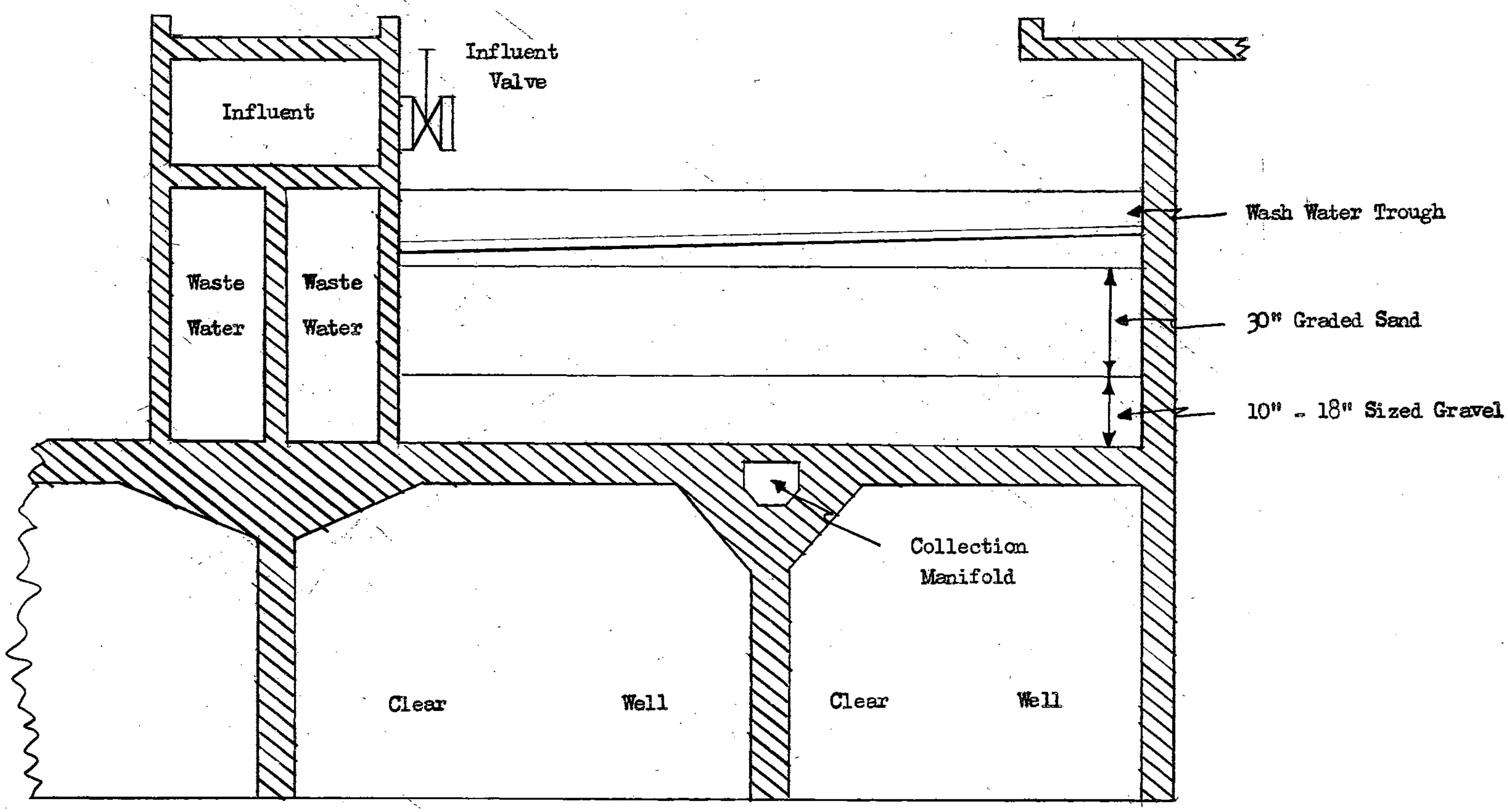

Figure No. I Cross Section of Typical Filter

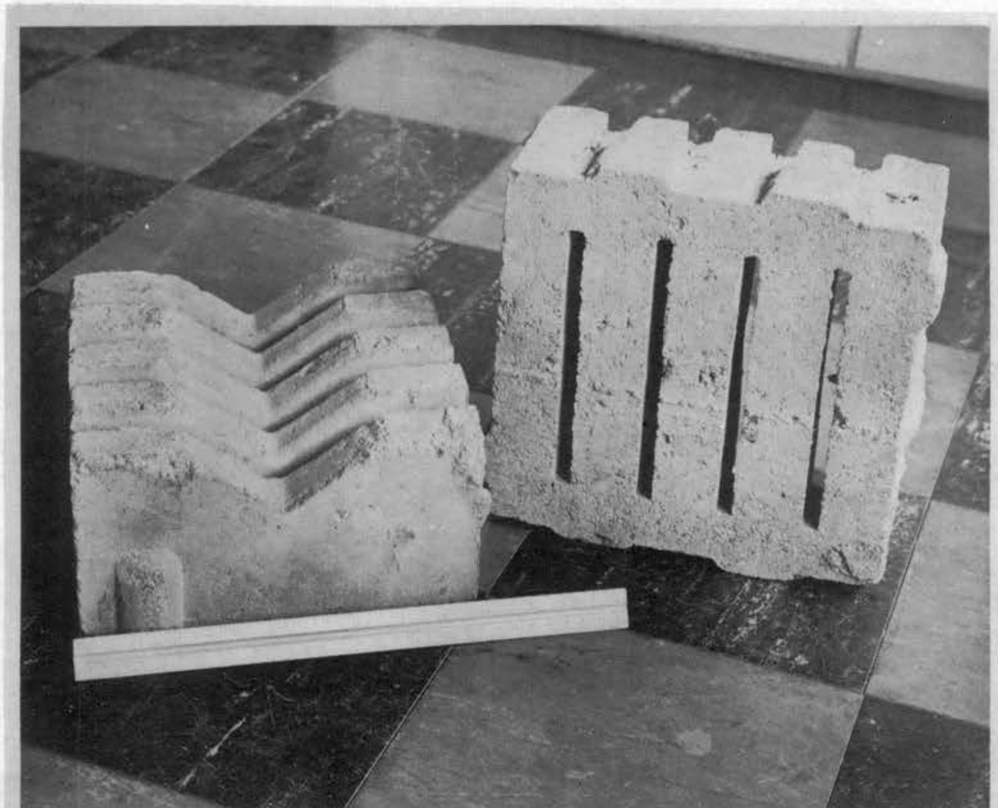

Figure II Wagner Block

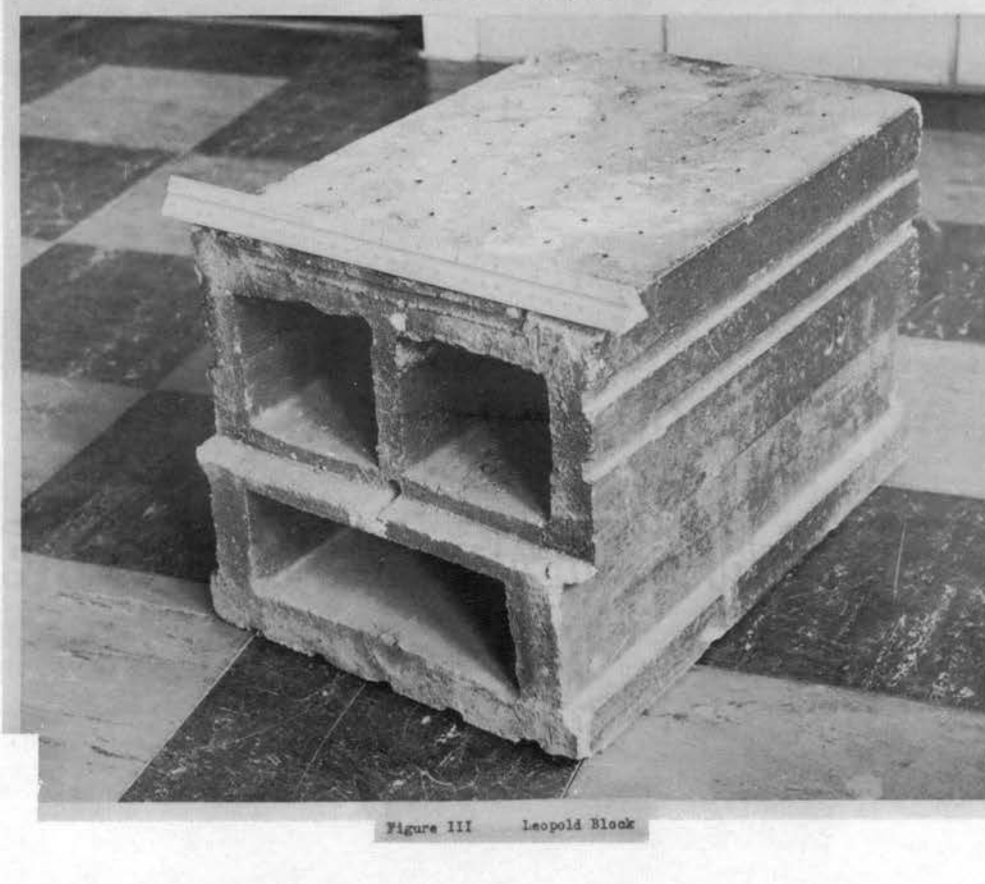

Figure III Leopold Block

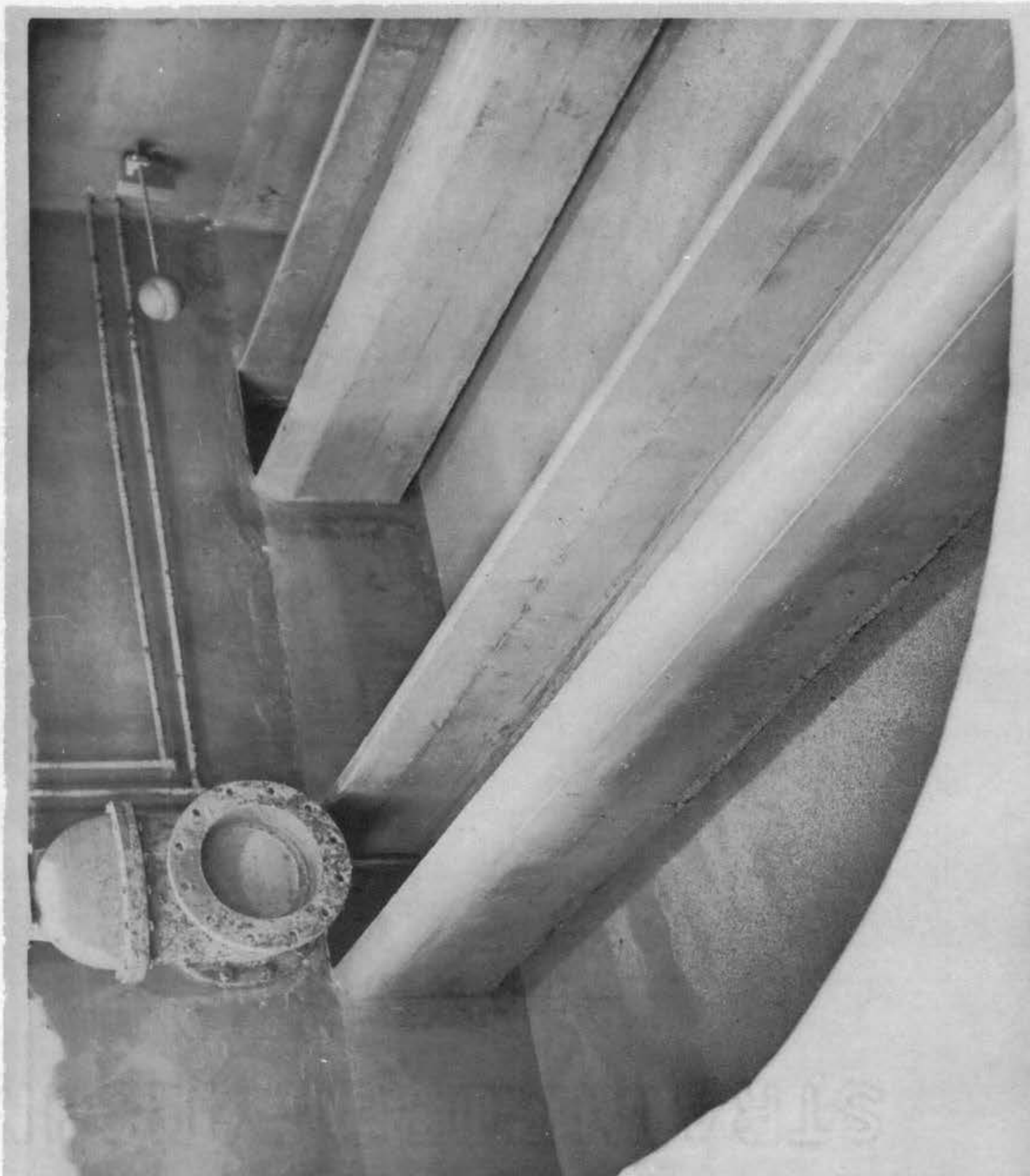

Figure IV View Filter No. II

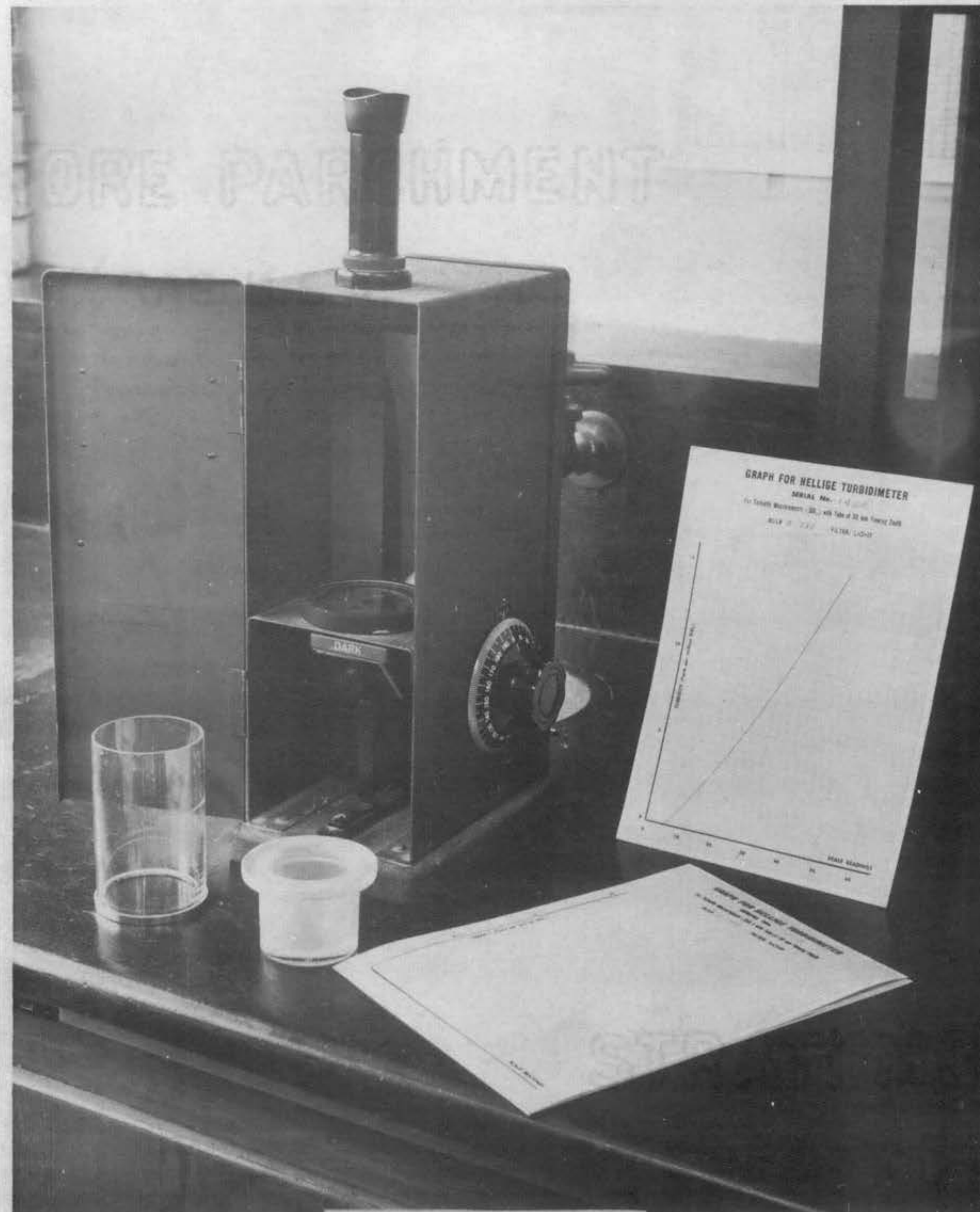

Figure V Turbidimeter

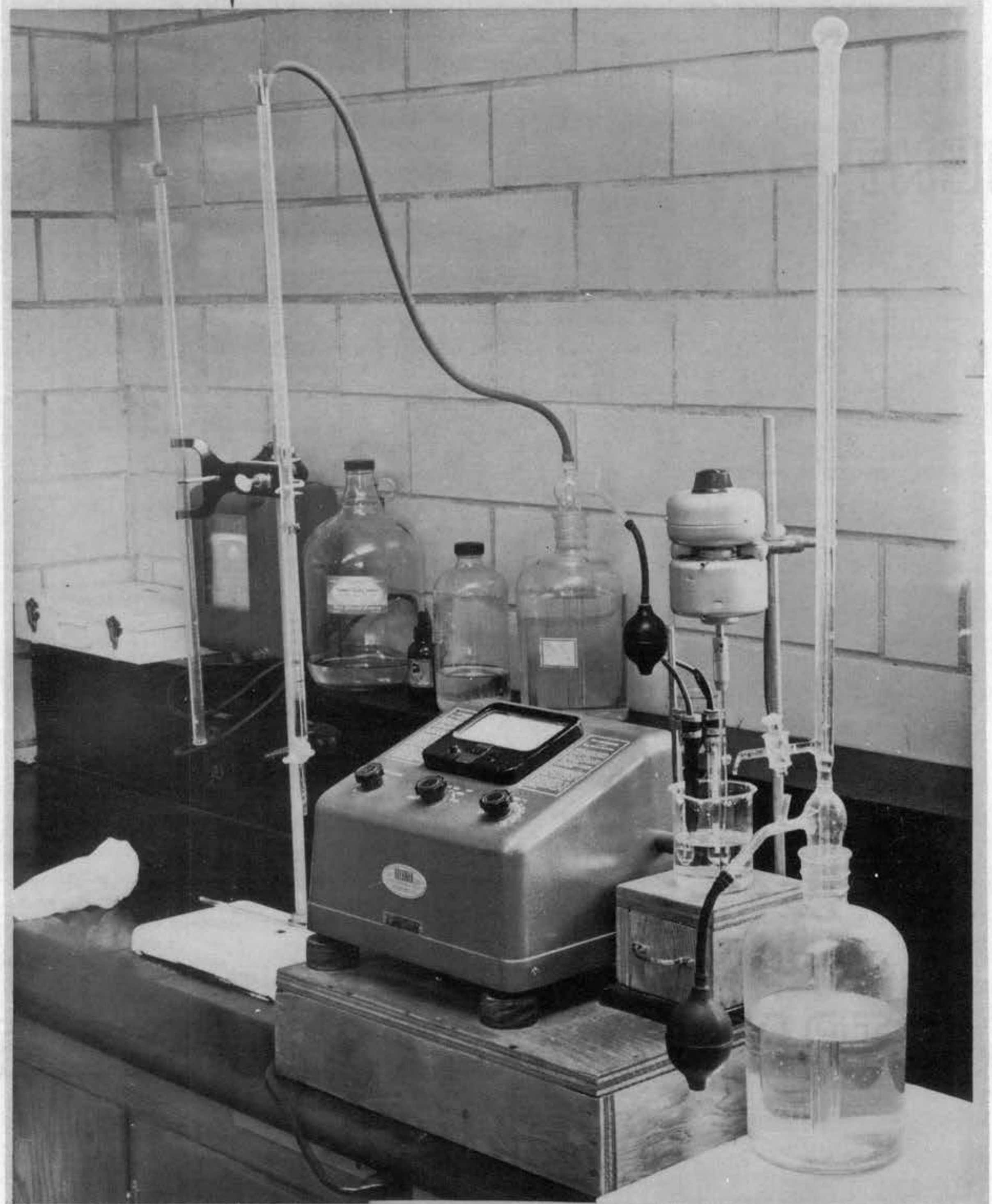

Figure VI pH Meter

CHAPTER V

PROCEDURE

It might be well at this time to discuss some points of interest on pretreatment of the water before filtration.

The alkalinity of the raw water during this test period ranged from 146 ppm to 161 ppm. The pH values ranged from 7.7 to 7.9. The temperature ranged from 57° to 70° F., and the turbidity range was 16 ppm to 32 ppm.

The plant consists of a design capacity of 1.0 M.G.D. "Accelator" manufactured by Infilco, Inc., and two design capacity 1.5 M.G.D. conventional design basins. These units are so designed that they can be run independent of each other, run parallel, or in series with each other. There are facilities for recarbonation at any of three points in the event softening of the water is desired.

Dosage of chemicals used, based on jar test, showed that for softening, 150 ppm of hydrated lime $Ca(OH)_2$ should be used and 12 ppm Aluminum Sulphate $Al_2(SO_4)_3 \ 18H_2O$ used. For coagulation, 40 ppm Aluminum Sulphate and 10 ppm hydrated lime were used.

For the first phase of this test, it was decided that approximately one-third of the water would be softened and two-thirds of the water be coagulated, with the two waters mixed just prior to application to the filters.

Following the procedure previously decided, one filter was held at a constant rate, while the other filters were varied according to the demand, and samples collected every four hours of the influent and effluent of the filters.

Turbidity, alkalinity, and pH were then determined for each sample and recorded.

The second phase of the test was to coagulate one-third of the water and soften two-thirds of the water with the two treated waters mixed just prior to application to the filters. With this treatment, it was found that the floc was too light to settle properly before applying the water to the filters, and as a result the filters became clogged at a very rapid rate.

Corrective measures were then taken by changing the flow as follows: One of the conventional basins was used to soften two-thirds of the water and the "Accelator" used to coagulate one-third of the water, with the two waters being mixed in the second conventional basins, followed by additional recarbonation. This treatment being satisfactory, the same series of tests as used in phase one was again followed.

In phase one and phase two, the additional records kept daily on each of the filters were: Hours the filter was operated; and gallons of water filtered.

It was decided that loss of head in a filter would govern when a filter was to be washed. This loss of head ranged from five feet to almost ten feet. The reason for this wide range of values is that at the start of the test it was arbitrarily set that at a loss of head of six feet the filter would be washed. Inasmuch as the filters were washed at night, it was left to the discretion of the operator as to the advisability of washing. Factors entering into this decision are such questions as: How heavy is the floc; how fast is the loss of head raising; is the filter to be run at the constant rate of one million gallons per day; and will the loss of head be too much twenty-four hours from now?

At the end of each filter run, the following values were recorded: Loss of head; total gallons of water filtered; total hours run; and gallons of wash water used. From these values, the per cent wash water was determined.

To reduce the probability of error in testing of samples, the author ran all tests and recorded all the values included in this thesis. All samples were collected by the author with the exception of the 0400 and 2400 hours samples.

The system of hourly designations is of the type used by the militia where there is a twenty-four hour operational basis with the hours running consecutively from 0100, being 1:00 A.M., and 2400, being 12:00 A.M.

DATE: October 6, 1952 TEMPERATURE: 69° F. FILTER NO. I

Coliform	Influent	0/5	Bacteria Count	Influent	1
	Effluent	0/5		Effluent	3
	Time	1900		Time	1900

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	1.5	0.9	1.0	12	116	5	104	8.8	8.4
0800	3.9	0.2	1.0	5	102	8	108	8.5	8.6
1200	2.5	0.2	1.0	0	109	0	109	8.0	8.2
1600	1.2	0.3	1.0	18	111	0	105	9.0	8.3
2000	2.0	0.5	1.0	3	107	0	106	8.4	8.4
2400	2.0	0.3	1.0	10	113	7	110	8.6	8.5

Hours Filter Run: 24

Gallons Filtered: 1,000,000

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 9, 1952 TEMPERATURE: 66° F. FILTER NO. I

Coliform	Influent	0/5
	Effluent	0/5
	Time	1600

Bacteria Count	Influent	10
	Effluent	0
	Time	1600

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	1.5	0.6	1.05	0	114	3	114	8.0	8.3
0800	1.5	0.4	0.95	9	112	3	114	8.6	8.3
1200	1.5	0.4	0.75	4	116	5	115	8.3	8.5
1600	1.8	0.3	0.75	6	114	4	115	8.8	8.5
2000	1.4	0.5	1.10	5	114	7	115	8.8	8.7
2400	3.1	0.4	0.22	0	120	3	111	8.2	8.35

Hours Filter Run: 24

Gallons Filtered: 866,300

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 17, 1952 TEMPERATURE: 63° F. FILTER NO. I

Coliform	Influent	0/5	Bacteria Count	Influent	1
	Effluent	0/5		Effluent	1
	Time	1400		Time	1400

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400			0.0						
0800	19.0	0.2	0.95	14	97	10	84	9.1	8.9
1200	7.0	0.3	0.8	6	96	6	99	8.6	8.7
1600	2.8	0.2	0.8	12	80	10	80	9.0	8.9
2000	4.2	0.3	0.8			7	98		8.7
2400									

Remarks on Treatment: Changed from parallel flow in basins to series flow; changed accelator from riser well to west basin, leaving Vort-Floc on - 1300 hours.

Hours Filter Run: 13.15

Gallons Filtered: 465,000

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 26, 1952 TEMPERATURE: 60° F. FILTER NO. I

Coliform	Influent	0/5
	Effluent	0/5
	Time	1600

Bacteria Count	Influent	3
	Effluent	1
	Time	1600

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	1.7	0.3	0.9	6	89	5	88	8.6	8.5
0800	1.8	0.7	1.0	7	91	4	85	8.7	8.5
1200	1.8	0.3	1.0	11	97	10	91	9.0	8.9
1600	2.5	0.3	1.0	6	96	7	94	8.7	8.8
2000	2.8	0.4	1.0	0	96	0	100	7.7	8.2
2400	1.5	0.2	1.0	0	97	0	100	7.9	8.1

Hours Filter Run: 23.0

Gallons Filtered: 960,000

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 9, 1952 TEMPERATURE: 66° F. FILTER NO. II

Coliform	Influent	0/5	Bacteria Count	Influent	10
	Effluent	0/5		Effluent	3
	Time	1600		Time	1600

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400			0						
0800	1.5	0.6	1.0	9	112	3	112	8.6	8.3
1200	1.5	0.7	0.8	4	116	4	115	8.3	8.4
1600	1.8	0.4	0.8	6	114	5	114	8.8	8.6
2000	1.4	0.5	0.75	5	114	5	114	8.8	8.6
2400			0						

Hours Filter Run: 14.25

Gallons Filtered: 537,700

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 11, 1952 TEMPERATURE: 64° F. FILTER NO. II

Coliform	Influent	0/5	Bacteria Count	Influent	2
	Effluent	0/5		Effluent	1
	Time	1600		Time	1600

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	1.0	0.5	1.0	11	113	5	102	8.9	8.6
0800	3.5	0.3	1.0	2	111	3	114	8.3	8.4
1200	1.5	0.3	1.0	2	110	2	109	8.3	8.3
1600	3.5	0.6	1.0	4	114	2	114	8.5	8.3
2000	2.0	0.4	1.0	4	114	4	109	8.5	8.6
2400	2.5	0.3	1.0	0	112	3	112	8.2	8.4

Hours Filter Run: 24.0

Gallons Filtered: 1,000,000

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 17, 1952 TEMPERATURE: 63° F. FILTER NO. II

Coliform	Influent	0/5	Bacteria Count	Influent	1
	Effluent	0/5		Effluent	2
	Time	1400		Time	1400

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400			0.0						
0800	19.0	0.1	0.8	14	97	10	84	9.1	8.9
1200	7.0	0.3	0.5	6	96	6	96	8.6	8.6
1600	2.8	0.2	0.5	12	80	10	81	9.0	8.9
2000	4.2	0.2	0.5			7	96		8.7
2400			0.0						

Remarks on Treatment: Changed from parallel flow in basins to series flow; changed accelator from riser well to west basin, leaving Vort-Floc on - 1300 hours.

Hours Filter Run: 12.7

Gallons Filtered: 312,400

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 23, 1952 TEMPERATURE: 62° F. FILTER NO. II

	Influent	0/5		Influent	7
Coliform	Effluent	0/5	Bacteria Count	Effluent	0
	Time	1400		Time	1400

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	2.0	0.2	1.0	0	98	0	110	7.5	7.8
0800	3.1	0.2	1.0	10	96	8	87	9.0	8.9
1200	2.0	0.2	1.0	1	98	3	97	8.3	8.4
1600	3.5	0.6	1.0	0	99	0	99	8.1	8.1
2000	2.8	0.5	1.0	0	96	0	96	7.9	8.2
2400	3.5	0.6	1.0	0	98	0	98	8.1	8.1

Hours Filter Run: 24

Gallons Filtered: 1,000,000

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 8, 1952 TEMPERATURE: 66^{o} F. FILTER NO. III

Coliform	Influent	0/5	Bacteria Count	Influent	1
	Effluent	0/5		Effluent	8
	Time	1600		Time	1600

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	2.8	1.5	1.0	0	115	0	118	8.2	8.1
0800	3.0	1.8	1.0	4	106	0	114	8.5	8.2
1200	3.1	1.1	1.0	2	112	0	111	8.3	8.2
1600	1.5	0.8	1.0	5	112	4	111	8.5	8.5
2000	1.2	0.5	1.0	8	112	6	111	8.6	8.5
2400			1.0						

Hours Filter Run: 24.0

Gallons Filtered: 1,000,000

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 13, 1952 TEMPERATURE: 64° F. FILTER NO. III

	Influent	0/5		Influent	1
Coliform	Effluent	0/5	Bacteria Count	Effluent	0
	Time	1600		Time	1200

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	2.9	0.8	- - - V A R Y I N G - - -	4	116	4	102	8.5	8.6
0800	2.7	0.3		14	102	4	112	9.1	8.5
1200	2.3	0.3		12	107	4	111	8.9	8.4
1600	2.4	0.5		10	110	4	109	8.7	8.5
2000	2.6	0.6		9	113	6	114	8.7	8.6
2400			0.0						

Hours Filter Run: 19.9

Gallons Filtered: 722,700

Wash Water Gallons: 0

Per Cent Wash Water: 0

arrangement of the equipment was as indicated in Figures 4 and 5.

The receiver and transmitter were put into operation and allowed to warm up for a period of thirty minutes. The klystron local oscillator was tuned until a maximum signal appeared on the monitor oscilloscope. At this time the reflection board position was varied to obtain a maximum signal return. This position remained fixed for the remainder of the experiment. During the tests it was occasionally necessary to make small adjustments of the klystron local oscillator to keep the receiver at its peak of sensitivity. This was necessary due to variations of wind velocity across the oscillator causing slight drift.

After the reflection board was adjusted for maximum reflection at zero degrees, readings were taken as rapidly as possible in the order shown in the data tables. These measurements were for rotation of the board in the horizontal plane. The first series of readings were taken with a blank board. That is, there were no conducting elements attached. The next series of readings were taken with nine elements attached to the board arranged symmetrically about the center of the board. The first group of measurements were for element spacings of one half wave length vertical and horizontal.

The second group of measurements were made with element spacings of one half wave length vertical. The horizontal spacing was an end-to-end arrangement. The spacings of the two groups of readings were as shown in Figure 6.

DATE: October 16, 1952 TEMPERATURE: 63° F. FILTER NO. III

	Influent	0/5		Influent	0
Coliform	Effluent	0/5	Bacteria Count	Effluent	1
	Time	1400		Time	1400

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	4.5	0.1	1.0	8	104	7	95	8.7	8.6
0800	23.0	0.2	1.0	17	92	12	74	9.2	9.0
1200	3.0	0.2	1.0	22	80	17	61	9.6	9.5
1600	3.5	0.1	1.0	8	92	8	93	8.9	8.8
2000	15	0.3	1.0	9	92	8	92	8.9	8.8
2400	1.3	0.2	1.0	13	101	6	92	8.8	8.7

Hours Filter Run: 24.0

Gallons Filtered: 1,000,000

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 25, 1952 TEMPERATURE: 62° F. FILTER NO. III

	Influent	0/5		Influent	1
Coliform	Effluent	0/5	Bacteria Count	Effluent	0
	Time	1400		Time	1400

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent P	Influent MO	Effluent P	Effluent MO	Influent	Effluent
0400	2.5	0.3		5	98	0	96	8.6	8.1
0800	1.8	0.2		5	95	3	95	8.5	8.5
1200	4.2	0.2	VARYING	5	97	4	94	8.7	8.4
1600	1.2	0.2				6	93		8.7
2000	2.0	0.2		0	98	7	98	8.2	8.5
2400			0.0						

Hours Filter Run: 22.0

Gallons Filtered: 755,400

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 9, 1952 TEMPERATURE: 66° F. FILTER NO. IV

Coliform	Influent	0/5	Bacteria Count	Influent	10
	Effluent	0/5		Effluent	10
	Time	1600		Time	1600

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	1.5	0.6	1.0	0	114	0	120	8.0	8.2
0800	1.5	0.5	1.0	9	112	3	118	8.6	8.3
1200	1.5	0.6	1.0	4	116	3	118	8.3	8.6
1600	1.8	0.6	1.0	6	114	4	115	8.8	8.6
2000	1.4	0.3	1.0	5	114	5	115	8.8	8.6
2400	3.1	0.3	1.0	0	120	3	118	8.2	8.3

Hours Filter Run: 24.00

Gallons Filtered: 1,000,000

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 14, 1952 TEMPERATURE: 64° F. FILTER NO. IV

Coliform	Influent	0/5	Bacteria Count	Influent	4
	Effluent	0/5		Effluent	3
	Time	1600		Time	1600

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	1.7	0.8	VARYING	17	115	7	100	9.0	8.6
0800	1.8	0.5		13	120	6	112	8.8	8.5
1200	1.3	0.4		9	118	6	113	8.7	8.6
1600	1.2	0.8		10	120	9	118	8.8	8.7
2000	2.6	0.3		11	122	7	115	8.8	8.6
2400	2.3	0.7		7	122	5	125	8.4	8.4

Hours Filter Run: 24.0

Gallons Filtered: 926,300

Wash Water Gallons: 0

Per Cent Wash Water: 0

DATE: October 17, 1952 TEMPERATURE: 63° F. FILTER NO. IV

Coliform — Influent 0/5, Effluent 0/5, Time 1400

Bacteria Count — Influent 1, Effluent 2, Time 1400

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	2.0	0.7	1.0	12	95	10	84	9.0	8.9
0800	19.0	0.1	1.0	14	97	10	83	9.1	8.9
1200	7.0	0.2	1.0	6	96	8	89	8.6	8.8
1600	2.8	0.1	1.0	12	80	10	81	9.0	8.9
2000	4.2	0.1	1.0			9	91	8.9	8.8
2400	3.1	0.1	1.0	0	94	1	93	7.9	8.3

Remarks on Treatment: Changed from parallel flow in basins to series flow; changed accelator from riser well to west basin, leaving Vort-Floc on - 1300 hours.

Hours Filter Run: 24.0

Gallons Filtered: 1,000,000

Wash Water Gallons: 36,000

Per Cent Wash Water: 3.6

DATE: October 25, 1952 TEMPERATURE: 63° F. FILTER NO. IV

Coliform	Influent	0/5	Bacteria Count	Influent	0
	Effluent	0/5		Effluent	0
	Time	1400		Time	1400

Hour	Turbidity		Rate of Flow MGD	Alkalinity				pH	
	Influent	Effluent		Influent		Effluent		Influent	Effluent
				P	MO	P	MO		
0400	2.5	0.3	1.0	5	98	0	93	8.6	8.1
0800	1.8	0.3	1.0	5	95	6	96	8.5	8.6
1200	4.2	0.3	1.0	5	97	4	95	8.7	8.5
1600	1.2	0.3	1.0	9	96	4	95	8.8	8.5
2000	2.0	0.5	1.0	0	98	4	99	8.2	8.4
2400	1.5	0.1	1.0	6	92	4	90	8.8	8.5

Hours Filter Run: 24.0

Gallons Filtered: 1,000,000

Wash Water Gallons: 0

Per Cent Wash Water: 0

FILTER NO. I

DATE		TURBIDITY Inf.	TURBIDITY Eff.	pH Inf.	pH Eff.	HOURS RUN	GALLONS FILTERED	LOSS OF HEAD	TOTAL GALLONS FILTERED	TOTAL HOURS RUN	WASH WATER GALS.	% WASH WATER
Oct.	3	3.1	0.9	8.8	8.4	24.0	958,700	9.5			50,000	
	4	2.3	0.9	8.8	8.4	13.0	518,800					
Oct.	5	2.6	0.9	8.7	8.5	19.0	746,600					
	6	2.2	0.4	8.6	8.4	24.0	1,000,000					
Oct.	7	2.5	0.8	8.8	8.4	10.95	288,500	6.0	3,508,600	90.95	45,000	1.3
	8	2.1	1.5	8.5	8.4	16.3	641,900					
Oct.	9	1.8	0.4	8.5	8.5	24.0	866,300					
	10	2.0	0.4	8.7	8.5	24.0	1,000,000					
Oct.	11	2.3	0.5	8.5	8.4	19.35	746,600					
	12											
Oct.	13	2.2	0.6	8.8	8.6	23.0	841,100					
	14	1.8	0.4	8.8	8.6	24.0	1,000,000					
Oct.	15	1.3	0.0	8.7	8.5	9.25	323,500					
	16	13.7	0.2	9.3	9.1	6.9	284,600	9.7	5,704,000	146.8	52,000	0.9
Oct.	17	8.3	0.2	8.9	8.8	13.15	776,100					
	18	2.5	0.3	8.6	8.4	24.00	990,000					
Oct.	19	3.1	0.3	8.5	8.5	7.85	232,000					
	20	2.6	0.3	8.8	8.8	12.7	524,800	5.5	2,532,900	65.0	45,000	1.8
Oct.	21	2.5	0.4	8.7	8.8	17.6	590,300					
	22	2.3	0.3	8.0	8.2	24.00	1,000,000					
Oct.	23	2.7	0.3	8.2	8.4	23.5	785,200					
	24	3.4	0.6	8.3	8.3	17.0	685,000					
Oct.	25	2.5	0.5	8.7	8.6	4.5	157,800					
	26	2.0	0.4	8.4	8.5	23.0	960,000					
Oct.	27	3.6	0.4	8.2	8.3	6.8	225,100	5.0	4,403,200	116.4	52,000	1.2
	28	2.8	0.4	8.8	8.8	4.7	158,800					
Oct.	29	3.2	0.5	8.5	8.6	11.25	328,000					
	30	2.9	0.5	8.3	8.4	24.0	950,000					
Oct.	31	3.3	0.4	8.4	8.3	14.6	471,400		1,898,200	54.55		

TABLE II

FILTER NO. II

DATE		TURBIDITY Inf.	TURBIDITY Eff.	pH Inf.	pH Eff.	HOURS RUN	GALLONS FILTERED	LOSS OF HEAD	TOTAL GALLONS FILTERED	TOTAL HOURS RUN	WASH WATER GALS.	% WASH WATER
Oct.	3	2.8	0.9	8.7	8.4	24.0	1,000,000	8.5	1,000,000	24.0	50,000	
	4	2.3	1.2	8.8	8.3	15.5	584,650					
Oct.	5	3.3	0.8	8.7	8.4	11.3	453,480					
	6	2.5	0.7	8.0	8.2	5.25	136,950					
Oct.	7	1.9	0.8	8.9	8.5	24.0	1,000,000					
	8	3.1	1.5	8.4	8.2	8.75	222,700					
Oct.	9	1.5	0.5	8.6	8.5	14.25	537,700					
	10	2.1	0.4	8.7	8.6	11.75	317,500	5.5	3,252,980	90.8	50,000	1.5
Oct.	11	2.3	0.4	8.5	8.5	24.0	1,000,000					
	12	4.6	0.9	8.7	8.6	22.15	858,400					
Oct.	13	2.5	0.5	8.9	8.5	13.5	354,700					
	14	1.5	0.4	8.7	8.5	8.5	215,450					
Oct.	15	1.4	0.2	8.7	8.5	24.0	1,000,000					
	16	3.3	0.1	9.2	9.1	13.5	480,300	6.0	3,908,850	105.6	52,000	1.3
Oct.	17	8.2	0.2	8.9	8.8	12.7	312,400					
	18	2.5	0.3	8.8	8.6	9.35	260,000	2.0	572,400	22.05	34,000	5.9
Oct.	19	2.3	0.3	8.6	8.5	24.0	1,000,000					
	20	2.1	0.6	8.4	8.6	8.2	153,700					
Oct.	21											
	22	2.3	0.3	8.1	8.2	16.0	646,000					
Oct.	23	2.8	0.4	8.2	8.3	24.0	1,000,000					
	24	3.5	0.6	8.3	8.3	7.5	179,000					
Oct.	25	2.7	0.4	8.7	8.7	9.95	407,150	5.5	3,385,850	89.65	50,000	1.5
	26					.75	29,600					
Oct.	27	3.0	0.4	7.9	8.2	24.0	1,000,000					
	28	3.3	0.3	8.1	8.3	16.0	505,900					
Oct.	29	3.0	0.3	9.1	8.7	1.8	50,500					
	30	3.0	0.4	8.5	8.5	17.0	636,000					
Oct.	31	3.0	0.4	8.2	8.2	24.0	1,000,000		3,222,000	83.55		

TABLE III

FILTER NO. III

DATE		TURBIDITY Inf.	TURBIDITY Eff.	pH Inf.	pH Eff.	HOURS RUN	GALLONS FILTERED	LOSS OF HEAD	TOTAL GALLONS FILTERED	TOTAL HOURS RUN	WASH WATER GALS.	% WASH WATER
Oct.	3	3.1	0.6	8.8	8.4	16.65	726,900					
	4	3.1	1.0	8.6	8.4	24.0	1,000,000					
Oct.	5							6.0	1,726,900	40.65	52,000	
	6	2.2	0.6	8.6	8.4	17.5	670,200					
Oct.	7	1.9	0.7	8.9	8.4	17.95	618,600					
	8	2.3	1.1	8.4	8.2	24.0	1,000,000					
Oct.	9	1.5	0.5	8.6	8.5	12.5	409,200					
	10	2.2	0.4	8.7	8.6	18.3	787,000					
Oct.	11	2.3	0.4	8.4	8.3	11.5	320,700					
	12	4.6	0.6	8.7	8.6	24.0	1,000,000					
Oct.	13	2.6	0.5	8.8	8.5	19.9	722,700					
	14	1.4	0.9	8.8	8.6	13.2	550,000					
Oct.	15	1.5	0.1	8.6	8.4	17.35	610,000					
	16	6.1	0.2	9.0	8.9	24.0	1,000,000					
Oct.	17	7.2	0.2	8.9	8.7	22.5	771,700					
	18	2.5	0.3	8.6	8.5	23.6	781,400					
Oct.	19	2.0	0.3	8.6	8.5	20.5	740,500					
	20	2.4	0.3	8.5	8.6	24.00	1,000,000					
Oct.	21	2.7	0.5	8.8	8.6	13.0	541,000					
	22	2.1	0.7	8.1	8.2	12.5	515,000					
Oct.	23	3.5	0.6	8.1	8.2	2.25	75,500	4.0	12,103,500	323.6	52,000	0.4
	24	3.4	0.5	8.3	8.3	24.0	1,000,000					
Oct.	25	2.2	0.3	8.6	8.4	22.0	755,400					
	26	2.1	0.3	8.4	8.5	16.0	587,000					
Oct.	27	2.9	0.2	8.0	8.2	18.8	629,000					
	28	3.1	0.4	8.3	8.4	24.0	1,000,000					
Oct.	29	3.2	0.6	8.3	8.4	21.0	750,700					
	30	2.1	0.6	8.2	8.1	10.8	294,900					
Oct.	31	3.1	0.4	8.3	8.3	17.5	580,900		5,597,900	154.1		

TABLE IV

FILTER IV

DATE		TURBIDITY		pH		HOURS RUN	GALLONS FILTERED	LOSS OF HEAD	TOTAL GALLONS FILTERED	TOTAL HOURS RUN	WASH WATER GALS.	% WASH WATER
		Inf.	Eff.	Inf.	Eff.							
Oct.	3	3.1	0.6	8.8	8.4	18.5	847,000					
	4	3.1	1.2	8.6	8.4	17.5	687,550	6.0	1,534,550	36.0	54,000	
Oct.	5	2.6	1.3	8.7	8.5	24.0	1,000,000					
	6	2.3	0.4	8.5	8.4	17.5	693,600					
Oct.	7	1.9	0.6	9.2	8.6	12.2	436,200					
	8	2.2	1.2	8.3	8.3	13.8	473,000	5.5	2,592,800	67.5	50,000	1.9
Oct.	9	1.8	0.5	8.5	8.4	24.0	1,000,000					
	10	2.0	0.4	8.7	8.5	20.0	588,500					
Oct.	11	2.6	0.3	8.4	8.3	17.1	557,900					
	12	5.4	0.8	8.8	8.7	12.7	491,000	4.0	2,637,400	73.8	50,000	1.9
Oct.	13	2.3	0.6	8.8	8.5	24.0	1,000,000					
	14	1.8	0.6	8.8	8.6	24.0	926,300					
Oct.	15	1.6	0.0	8.7	8.5	20.0	538,300					
	16	7.7	0.5	9.1	9.0	14.0	483,400	7.2	2,948,000	82.0	52,000	1.7
Oct.	17	6.4	0.2	8.8	8.8	24.0	1,000,000	5.1	1,000,000	24.0	36,000	3.6
	18	2.6	0.4	8.7	8.5	11.8	391,500					
Oct.	19	2.4	0.3	8.6	8.6	8.5	340,500					
	20	2.6	0.3	8.6	8.6	17.8	746,300					
Oct.	21	2.2	0.4	8.5	8.7	24.0	1,000,000					
	22	2.0	0.2	8.0	8.3	5.95	187,900					
Oct.	23	2.8	0.3	8.3	8.4	12.55	538,500					
	24	3.2	0.6	8.3	8.4	12.55	549,700					
Oct.	25	2.3	0.2	8.6	8.4	24.0	1,000,000					
	26	1.9	0.4	8.8	8.7	15.1	506,900					
Oct.	27	3.3	0.2	8.0	8.2	16.5	474,500					
	28	3.5	0.4	8.5	8.5	12.55	510,500	5.5	6,246,300	165.3	52,000	0.8
Oct.	29	3.2	0.5	8.3	8.3	24.0	1,000,000					
	30	2.9	0.4	8.7	8.6	12.4	448,400					
Oct.	31	3.3	0.3	8.6	8.4	12.8	387,500		1,835,900	49.2		

TABLE V

CHAPTER VI

SUMMARY AND CONCLUSION

Conclusion from data is at times somewhat misleading; therefore, in the summary and conclusion as to the characteristics of rapid sand filters, not only will the data collected be used, but also observations and other findings incorporated in order that a more complete and accurate conclusion may be ascertained. For clarity, findings on each filter will be made separately and then collectively.

Filter No. I ran a total of 464 hours, filtered 18,047,000 gallons of water, and had an average per cent wash water used of 1.3%. The percentage removal of turbidity ranged from 15% up to 99% with an over-all average of 84%. This filter showed a tendency to air bind as the loss of head increased, also, a number of small mud balls were noticed and an increase in the sand bed was noted.

Filter No. II ran a total of 392 hours, filtered 15,342,000 gallons of water, and had an average per cent wash water used of 2.5%. The percentage removal of turbidity ranged from 15% up to 99% with an over-all average of 81%. This filter had very little tendency to air lock, and very little increase in the sand bed.

Filter No. III ran a total of 478 hours, filtered 19,428,000 gallons, and had an average per cent wash water used of 0.4%. The percentage removal of turbidity ranged from 7% up to 99% with an over-all average of 83%. This filter had "Anthrafilt" as a filter media, which is much coarser than the sand in the sand filter. It was noticed that after the filter was washed, regardless of how long it was out of operation before re-using, that the per cent removal of turbidity was very low, but that in a very short period of time, after being put into operation, the per cent removal became higher, up to about the average for this filter. It was also noticed that in this filter there was a very marked cracking of the filter bed and a pulling away from the side walls, due to growth of the filter bed. It is believed that unless corrective measures are taken the present continued practice will result in the complete clogging of this filter. As corrective measures, it is suggested that one of the following or a combination of the same be employed: installation of a surface wash; increase the frequency of washing; or raise the height of wash water trough.

Filter No. IV ran a total of 498 hours, filtered 18,774,000 gallons of water, and had an average per cent wash water used of 2.0%. The percentage removal of turbidity ranged from 4% up to 99% with an over-all average of 83.5%. This filter would air bind each time the loss of head reached a value of between 6 and 7 feet, and when the binding would start, the head loss increased very rapidly, 3 to 4 feet in an additional 8 hours run. There seemed to be no decrease in the effectiveness of the filter with these rapid increases in loss of head, but at a head loss of approximately 9 feet, the rate of flow would gradually fall off.

In summarizing the data, the following values were found:

Filter No.	Turbidity Removal %	Total Gallons Filtered	Total Hrs. Run	Wash Water Per Cent
I	84	18,047,000	464	1.3
II	81	15,342,000	392	2.5
III	83	19,428,000	478	0.4
IV	83.5	18,774,000	498	2.0

From the foregoing figures, it may be concluded that regardless of the design of a filter, a very high percentage of turbidity removal is accomplished, provided there is a properly conditioned water being filtered. It was also noted that the per cent removal of turbidity increased as the turbidity of the water on the filters increased.

Over-all average of the four filters was very near the average for each filter. Over-all average of turbidity on the four filters was 2.9, while the over-all effluent turbidity was 0.43, which amounts to an over-all removal of turbidity of 83%.

From further summation of the data, we have the following values:

Filter No.	Hours Run between Washing	Amount Wash Water Used
I	105	194,000
II	77	186,000
III	324	52,000
IV	83	240,000

It may be readily seen from the above and preceding figures that Filter No. III produced the best results as far as length of run before washing. Based on the above figures, and assuming the cost of water at $0.07 per thousand gallons, it may be surmised that a saving of a minimum of $113.00 per year, and a maximum of $158.00 per year per filter could be accomplished, if each filter were as efficient as Filter No. III on wash water only.

In conclusion, it is believed that regardless of the design of a rapid sand filter, there is no substitute for properly treated water.

Even with the use of a very poor designed filter, a very good water may be obtained by intellective treatment and operation. Again it is emphasized that rapid sand filters are only strainers for the removal of turbidity and that the purification of the water is dependent upon other means.

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